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A real time scintillating fiber Time of Flight spectrometer for LINAC photoproduced neutrons

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ABSTRACT

The use of high-energy (> 8 MeV) LINear ACcelerators (LINACs) for medical cancer treatments causes the photoproduction of secondary neutrons, whose unwanted dose to the patient has to be calculated. The characterization of the neutron spectra is necessary to allow the dosimetric evaluation of the neutron beam contamination.

The neutron spectrum in a hospital environment is usually measured with integrating detectors such as bubble dosimeters, Thermo Luminescent Dosimeters (TLDs) or Bonner Spheres, which integrate the information over a time interval and an energy one.

This paper presents the development of a neutron spectrometer based on the Time of Flight (ToF) technique in order to perform a real time characterization of the neutron contamination. The detector measures the neutron spectrum exploiting the fact that the LINAC beams are pulsed and arranged in bunches with a rate of 100–300 Hz depending on the beam type and energy. The detector consists of boron loaded scintillating fibers readout by a MultiAnode PhotoMultiplier Tube (MAPMT).

A detailed description of the detector and the acquisition system together with the results in terms of ToF spectra and number of neutrons with a Varian Clinac iX are presented.

1. Introduction

The use of high-energy LINear ACcelerators (LINACs) for medical cancer treatments is widespread on an international scale. External radiotherapy high energy (> 8 MeV) photon beams produce neutrons in their interaction with the high Z materials in the accelerator head, mainly because of the Giant Dipole Resonance reaction [1].

The LINAC beam neutron contamination causes an undesirable dose delivered to the patient. For instance, Huang et al. [2] estimated that for a 4 mm tungsten target and incident electron energy of 18 MeV the photoneutron equivalent dose is 0.231 mSv/GyX-ray at the isocenter. The exposure to neutrons may become a risk to the patient [3–5], and thus has to be evaluated, a task which requires spectrometric measurements [6].

This paper describes the development of a real time neutron spectrometer based on boron loaded plastic scintillator fibers exploiting the $^{10}B(n,\alpha)^{7}Li$ neutron capture reaction. The fibers are readout by a MultiAnode PhotoMultiplier Tube (MAPMT) with dedicated electronics (Sections 2 and 3), designed to allow the neutron detection in the heavily γ contaminated hospital environment.

The detector has been designed to obtain Time of Flight (ToF) neutron spectra. Since the neutron path length is in principle unknown, the ToF spectra are needed in order to unfold the energy spectra to calculate the additional dose. This work proves the working principle and features of such a detector, while the dose evaluation will be the subject of future publications. Given that the resolution of energetic spectra calculated with ToF methods is related to the temporal resolution of the detector [7], the device has been designed in order to achieve a high temporal resolution. Furthermore it allows the measurements of ToF spectra in real time.

The detector has been tested at the Radiotherapy Unit of the Sant'Anna hospital in Como (Italy); the set-up and the results are presented and discussed in Sections 4–6.

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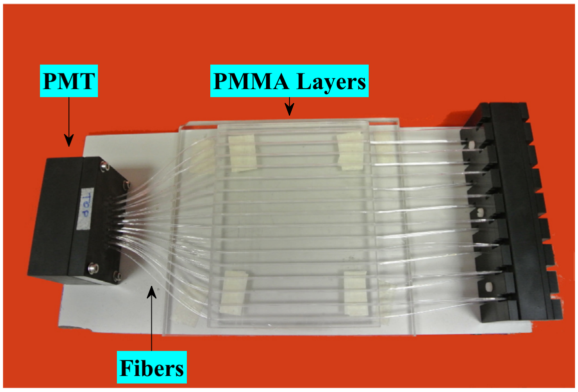

Fig. 1. The neutron ToF detector.

2. The detector and its front-end electronics

The sensitive head of the ToF detector (Fig. 1) consists of 16 groups of round single clad fibers: 2 of them, the external ones, are single 1 mm diameter BCF-10 fibers (by Saint Gobain[1]), while the others are composed of a group of 4 BC-454, 0.5 mm diameter fibers (by Saint Gobain). The length of the fibers varies in the range between 25 and 27 cm and the space between two groups of fibers is around 0.8 cm. The groups of fibers are placed in grooves between two 0.5 cm thick layers of PolyMethylMethAcrylate (PMMA) with an area of $13 \times 13\ \text{cm}^2$. The BCF-10 fibers are general purpose ones and are not discussed in this paper [8], while the BC-454 fibers have the following elemental composition: (87%) ^{12}C, (8%) ^{1}H and (5%) natural boron (1% is ^{10}B). The BC-454 exploits the ^{10}B(n,α)^{7}Li reaction for the thermal neutron (~0.025 eV) detection given its neutron capture cross-section is 3980 bn [9].

One side of each fiber group is interfaced to one channel of the Hamamatsu H7260K linear array MAPMT biased at −800 V. The MAPMT is inserted in a black support of PolyOxyMethylene (POM) that holds also the coupling system between the fibers and the MAPMT itself. The fibers have been glued in the support with a two-component resin (100 parts of a liquid epoxy resin solvent and 60 parts of an amine-based hardener, produced by Prochimia[2]) and the end of the fibers has been manually polished with sandpaper of different grit size.

Even though the MAPMT has 32 channels only 16 have been used in order to increase the distance between two adjacent fibers with the purpose to reduce the cross-talk between channels.

The MAPMT detector used in the present work has a 0.8 mm thick borosilicate glass window, which usually has a boron oxide content in the range 5–30%. As a result, the neutrons can be captured not only by the fibers but also by the PMT window.

The signals coming from the MAPMT are digitized by the Front-End Electronics (FEE) based on the MultiAnode ReadOut Chip (MAROC) 3 ASIC [10]. The MAROC ASIC is hosted on a custom board (Fig. 2) whose main parts are:

- The MAROC ASIC itself.
- The PMT socket, used to directly connect the MAPMT to the board.
- Two Altera[3] Cyclone II FPGAs, for the ASIC configuration and the generation of the readout sequence.
- A 12 bit AD9220 ADC.

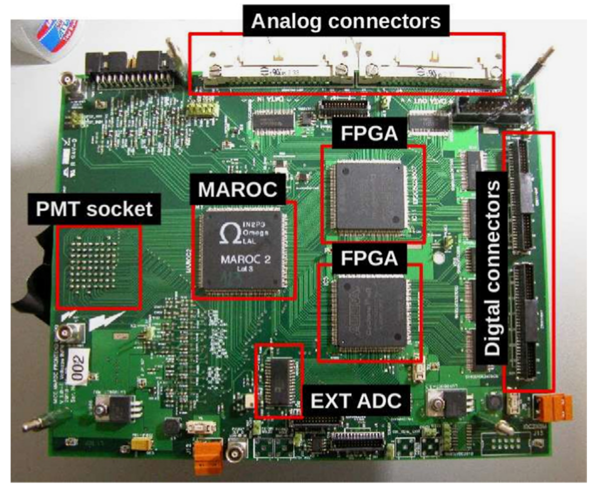

Fig. 2. The MAROC3 board.

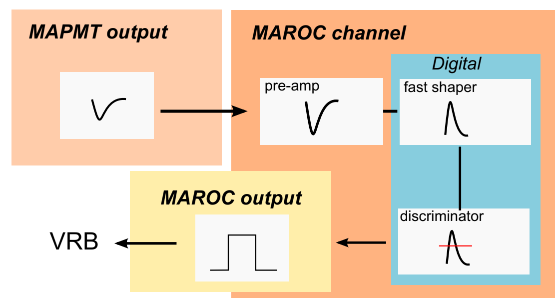

Fig. 3. Single channel digital signal treatment with the MAROC3 board [11].

- Two analog connectors, used for the configuration and the analog readout.
- Two digital connectors, where the digital signals coming from the ASIC are addressed to.

The MAROC3 Board is powered with an Agilent E3631A Triple Output DC Power at 5 V.

Each of the MAPMT anode outputs coupled with the fibers (16 out of 32) is connected with the MAROC inputs (PMT socket). For each channel (Fig. 3), the PMT signal is first amplified by a 8-bit variable gain pre-amplifier (up to a factor 4). Each MAROC channel has an analog and a digital output, but for the ToF measurements here reported only the digital one has been used. The amplified signal is fed to a fast (15 ns) unipolar shaper followed by a discriminator (10 bit DAC) leading to the production of 64 digital trigger outputs.

The digital output is a pulse whose width is a function of the input amplitude because of a Time over Threshold (ToT) architecture (Fig. 4). The MAROC discriminator output is correlated with the input amplitude and can be described with a power-of-4 polynomial law [12]. The pulse width (that is the time the signal stays above threshold) is an information used in the neutron signal discrimination as described in Section 3.

A VME Readout Board (VRB) is used as an interface between a PC and the MAROC board; it allows sending the initial configuration to the ASIC and processing its output data. The MAROC3 configuration is performed by the user with a Graphical User Interface (GUI) developed in Tcl/Tk.[4] During the data taking the

[1] Saint-Gobain Crystals, http://www.detectors.saint-gobain.com/Default.aspx.

[2] For further information http://www.prochima.com/eng/product.asp?id=15, E-30 water effect resin.

[3] Altera Corporation, Cyclone II FPGA http://www.altera.com/devices/fpga/cyclone2/cy2-index.jsp.

[4] Tcl (Tool Command Language) is a dynamic programming language and Tk is its Graphical User Interface ToolKit, http://www.tcl.tk.